APPENDIX A
ST. LUCIE ESTUARY/INDIAN RIVER LAGOON CONCEPTUAL MODEL

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INTRODUCTION

The St. Lucie Estuary, a major tributary of the Indian River Lagoon, is located on the southeastern coast of Florida. It discharges into the Indian River Lagoon and the Atlantic Ocean through the St. Lucie Inlet. The estuary encompasses approximately 8 square miles (Steward et al., 1994). The 930-square kilometer Indian River Lagoon also receives major discharges from Taylor Creek, the C-25 Canal, Moores Creek, and the Virginia Avenue Canal to the north of the St. Lucie Estuary (Woodward-Clyde, 1994). The Fort Pierce Inlet provides an additional connection between the southern Indian River Lagoon and the ocean. No major Indian River Lagoon tributaries exist from the St. Lucie Inlet south to the Jupiter Inlet.

The model boundary for the St. Lucie Estuary/Indian River Lagoon Conceptual Model extends south to the Indian River Lagoon Surface Water Improvement and Management (SWIM) boundary at the Jupiter Inlet and north to the St. Lucie County line, which is north of the Fort Pierce Inlet. To include the nearshore reef tract, the model extends 3 miles eastward into the Atlantic Ocean. The western boundary includes the open channel headwaters of the North and South Forks of the St. Lucie River and the coastal structures on the C-23, C-24, and C-44 Canals (**Figure A-1**).

Extensive urban and agricultural drainage projects have resulted in hydrologic changes in the watershed of the southern Indian River Lagoon. Approximately 3 inches or 125,000 acre-feet of water storage has been lost. Storm water runoff has increased from 11.2 to 15.7 inches per year and peak runoff rates are higher. Historically, 60 percent of all flows to the St. Lucie Estuary came from the North Fork of the St. Lucie River. Currently, only 25 percent of the runoff flows to the estuary through this historic route. Runoff has increased substantially, from a historic level of 3 percent to 25 percent. Much of this runoff flows through the C-23 Canal, which is an artificial connection into the confluence of the North and South Forks of the St. Lucie River. Along with these hydrologic and land use changes has come a 100 percent increase in phosphorous loading and a 200 percent increase in nitrogen loading.

The drainage projects that have caused these hydrologic changes include the C-23, C-24, C-25, and C-44 Canals, which are part of the Central and Southern Florida (C&SF) Project, as well as smaller secondary and tertiary drainage canals that cross the landscape and direct storm water runoff to the primary canals. Flows that historically made their way slowly through natural wetlands in the C-25 basin to the North Fork of the St. Lucie River now dump directly into the C-25 Canal, which empties into the area of the Indian River

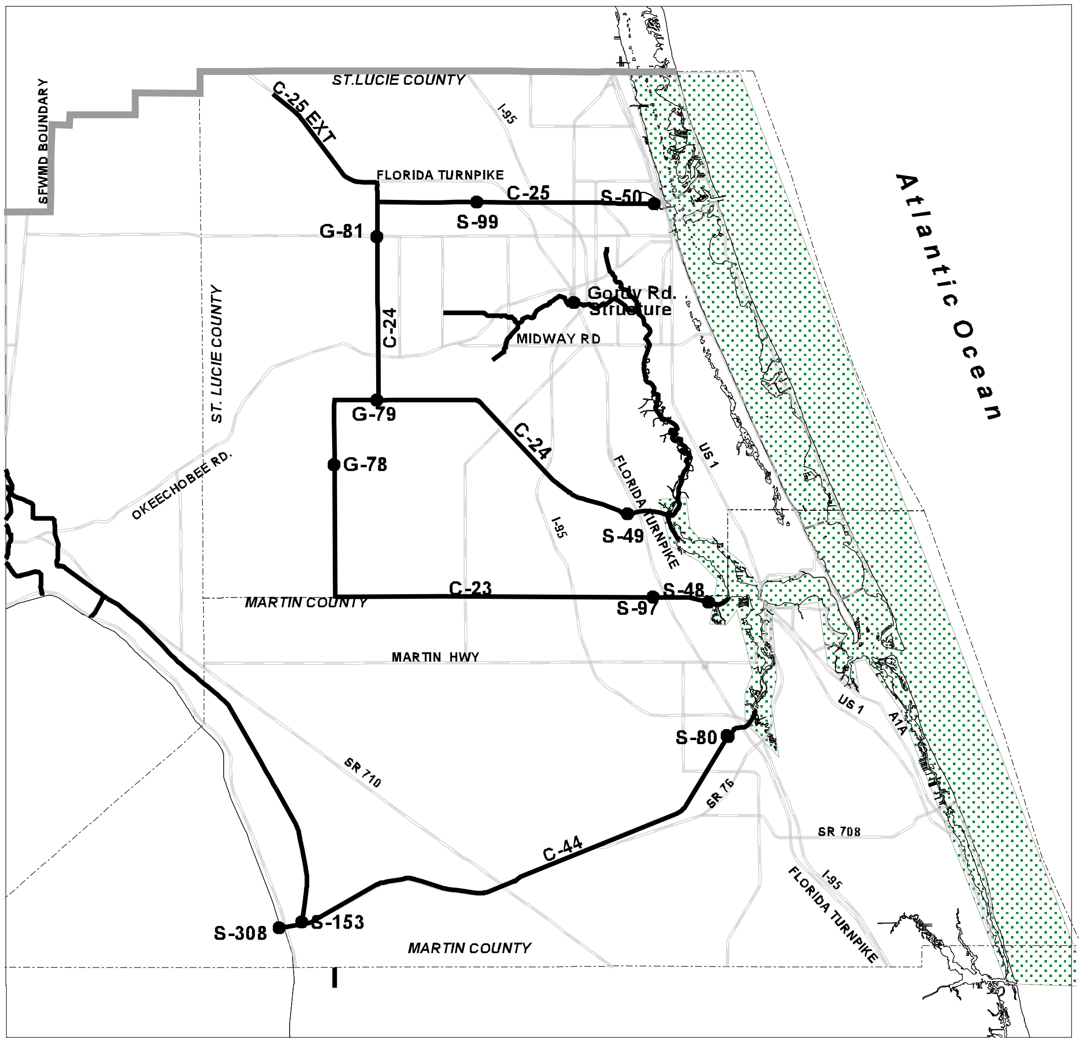

Figure A-1. Indian River Lagoon/St. Lucie Estuary Conceptual Model Boundary

Lagoon around the Fort Pierce Inlet. In addition, the St. Lucie Canal (C-44) provides a link from the St. Lucie Estuary to the lake that did not existed historically. This canal is used to navigate from the St. Lucie Inlet to Lake Okeechobee and to release floodwaters from Lake Okeechobee to tide.

The major effects of anthropogenic changes in the watershed are significant alterations in the timing, distribution, quality, and volume of fresh water entering the estuaries (Steward et al., 1994). Alterations in timing include excess wet season flows and insufficient dry season flows. Despite these impacts, the St. Lucie Estuary and Indian River Lagoon continue to be important resources, with significant environmental and economic values. Understanding how these systems respond to stress will provide a basis for well informed management decisions on restoration activities.

CONCEPTUAL MODEL APPROACH

Participants in a series of interagency workshops, held from August 1999 to November 2000, developed the framework for a conceptual model of the St. Lucie Estuary and the Indian River Lagoon. The conceptual model is structured to support the applied science strategy currently being implemented in the restoration coordination and verification (RECOVER) monitoring and assessment process. The RECOVER monitoring is a major component of the Comprehensive Everglades Restoration Plan (CERP). The St. Lucie Estuary/Indian River Lagoon Conceptual Model identifies the major ecological stressors in the St. Lucie River and Estuary watershed, the ecological and biological effects they have on the ecosystem, and the attributes in the natural systems that are the best indicators of the changes that have occurred as a result of the stressors (USACE and SFWMD, 1999). The basic features of this model are represented in **Figure A-2**. These features are discussed below.

Sources of Ecological Stress

Sources of ecological stress, or external drivers, in the St. Lucie Estuary and the Indian River Lagoon originate from agricultural and urban development and the ensuing construction and operation of water management systems. These sources originate in both local watersheds of the estuary and lagoon and in the larger drainage basins of Lake Okeechobee. Sea level rise is also a factor that affects the ecology of the lagoon system and must be taken into consideration during restoration efforts.

Ecological Stressors

The ecological stressors affecting the St. Lucie Estuary and the Indian River Lagoon are altered hydrology, altered estuarine salinity, input and elevated levels of nutrients and dissolved organic matter, input of contaminants, boating and fishing pressure, and physical alterations to the estuary.

The hydrology and estuarine salinity of the St. Lucie Estuary and the Indian River Lagoon are altered by Lake Okeechobee regulatory releases, basin flood releases, and basin water withdrawals result in altered freshwater flow volume and timing. Water is released from Lake Okeechobee when the lake stage exceeds the stage set in its regulatory schedule, to maintain or enhance environmental conditions in the lake, and to protect agricultural and urban land uses from flooding. Water is withdrawn from Lake Okeechobee during dry periods to fulfill agricultural and urban water demands. Also, sea level rise affects the hydrology and salinity of the St. Lucie Estuary and the Indian River Lagoon.

Agricultural and urban land use practices have resulted in the input and elevated levels of nutrients and dissolved organic matter. Other contaminants, such as pesticides and herbicides, also originate from these practices. These are discharged into the estuary via the canal system and overland flow.

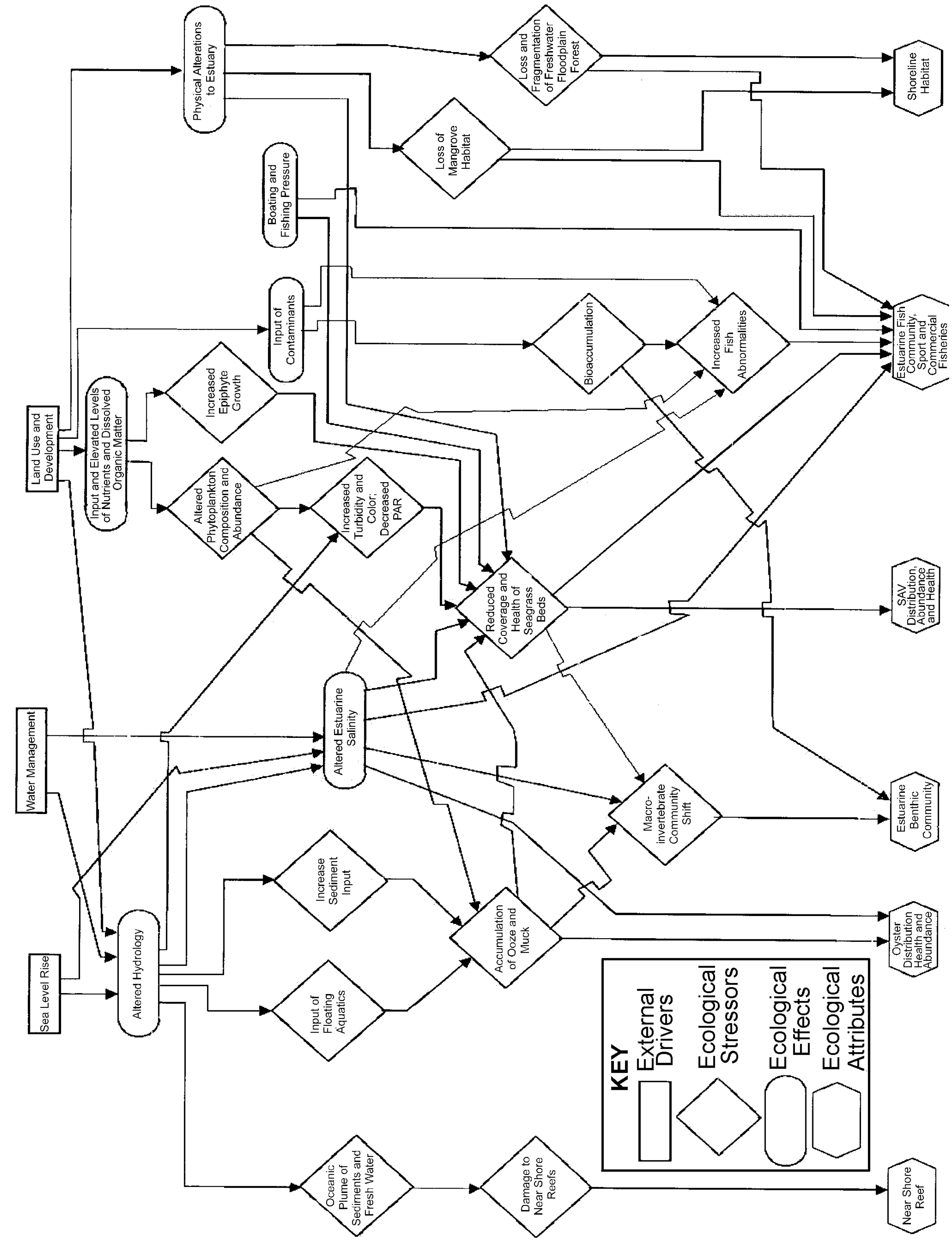

Figure A-2. St. Lucie Estuary/Indian River Lagoon Conceptual Model

Boating and fishing pressure also stress the ecological system. The number of boats utilizing the waterways is rapidly increasing and their support facilities can have adverse impacts on water quality and resources of the lagoon. Fishing pressure began in the 1890s with the development of a commercial industry in the area. With increases in population, the pressure from recreational fisheries may become a larger problem.

Physical alterations to the estuary also impacts the estuary. These alterations are caused by inlet construction and maintenance, and the development of the shoreline and adjacent wetlands of the estuaries and their tributaries.

Ecological Effects of Stressors

Changes in the distribution and timing of water have resulted in both low salinity and hypersalinity events. Salinity is one of the principal factors influencing the distribution and abundance of organisms inhabiting estuaries (Kennish, 1990). The alteration of estuarine salinity zonation has had an overwhelming ecological impact on the St. Lucie Estuary and the Indian River Lagoon.

Regulatory water releases from Lake Okeechobee result in the transport of massive volumes of organic and inorganic sediments. These sediments contribute to the deposits of ooze and muck in the estuaries (Shrader, 1984; Gunter and Hall, 1963; Pitt, 1972). The large accumulations of muck covering the bottom of the estuary dramatically decrease the quality and quantity of habitat for everything from benthic macro invertebrates to oysters and fin fish. High volume releases create an oceanic plume of colored water and suspended solids extending into the Atlantic Ocean out to the nearshore reef.

Together, altered salinity and siltation negatively effect every component of the estuarine and nearshore reef ecosystems, including submerged aquatic vegetation, phytoplankton, fish and macro invertebrate communities, fisheating birds, reef building polychaetes, and the nearshore reef community (Haunert, 1988). The recurring high flow conditions in the St. Lucie Estuary have reduced the numbers of oysters dramatically and the frequency at which these high flows occur have prevented recovery, which takes 3 to 5 years after each prolonged freshet (Cake, 1983). Damage to the nearshore reef habitat, especially the chicken-liver sponges, can produce secondary effects on juvenile green sea turtles that feed on the sponges (Browder, personal communication, 2000). Altered salinity, sudden drops in salinity, or salinity fluctuations are significant stressors to fish and shellfish populations. Lowered salinity and freshwater conditions are conducive to the persistence of fish pathogens, especially fungi, that are found in lesioned fish found in the St. Lucie Estuary (Landsberg, 2000).

The loss and fragmentation of shoreline habitat and the increase in the input of nutrients, dissolved organics, and toxins have exacerbated these problems (Steward et al., 1994). The loss and fragmentation of habitat due to development results in the direct loss of mangrove wetlands and emergent bank vegetation, upon which fish and macro invertebrate communities depend. Increased inputs of nutrients and dissolved organics degrade water quality, contribute to the accumulation of muck, and contribute to changes in phytoplankton communities, macro algae, and submerged aquatic vegetation. Increased input of toxins from agricultural runoff, urban development, and the boating industry, including metals, pesticides and their residues, may lead to bioaccumulation in aquatic food chains leading to fish eating birds. This is one of the factors leading to increased incidence of fish abnormalities in the estuary (Gabriel, 1999). A decrease in the numbers, diversity, and health of fisheries can have secondary effects on the health and mortality of the resident dolphin population in the Indian River Lagoon (Browder, personal communication, 2000).

Ecological Attributes

Nearshore Reef

A nearshore reef forms bands of unique marine habitat 2 to 3 miles offshore of the Atlantic Coast between the St. Lucie and Fort Pierce Inlets. This worm reef, built by *Sabellarid polychaetes*, is very susceptible to silt and salinity variation. The nearshore reef is the northern extent of nonreef building corals. Shallow reef corals reach their northern limit on inshore rock formations adjacent to the St. Lucie Inlet and Jupiter Island, while inshore rock and Sabellarid and algal reefs proceed further north to Cape Canaveral (Zale and Merrifield, 1992; Jaap and Hallock, 1991). Major live coral reefs, *Oculina varicosa,* are only abundant on the shelf edges that occur at depths of 60 to 100 meters.

These complex rock, Sabellarid, and coral structures create benthic fish habitat diversity on the continental shelf resulting in increased biodiversity of lagoon fish in the St. Lucie Inlet (Gilmore, 1995). Approximately 66 percent of the sea grass fishes in the lagoon are species that spawn on the continental shelf (Gilmore, 1988). Also, the nearshore reef is habitat for juvenile green sea turtles.

The continental shelf fish biodiversity is greatly influenced by various reef structures and sediment. The nearshore reef is adversely affected by high level discharges and the resulting silt and salinity plumes that occur mostly to the south of the St. Lucie and Fort Pierce Inlets.

Oyster Distribution Health and Abundance

Oysters and other bivalves, such as mussels and *Rangia,* are sensitive to salinity and siltation in the St. Lucie Estuary and the Indian River Lagoon. Under natural conditions, oyster reefs can be very large and provide extensive attachment area for oyster spat and numerous associated species such as mussels, tunicates, bryozoans, and barnacles (Woodward-Clyde, 1998). Several studies have found over 300 faunal species in oyster beds, including other mollusks, crustaceans, annelids, numerteans, flatworms, sponges, coelenterates, and protozoa (Pearse and Wharton, 1938; Wells, 1961; Bahr and Lanier, 1981).

Historically, oysters were abundant in the estuary and lagoon, covering 1,400 acres. Presently, their distribution is limited to approximately 200 acres. A restoration target of approximately 900 acres of healthy oyster beds has been set. To achieve this, a conducive salinity distribution must be reestablished in areas that provide a potentially suitable bottom habitat. Oysters require soft sediments with little surface structure or roughness. These areas are located using the St. Lucie Estuary Geographic Information System (GIS) Application Model (Woodward-Clyde, 1998).

Work done on oysters in the past documents slightly different preferred ranges and mortality thresholds, these various studies are summarized in the 1998 Woodward-Clyde report. The exact thresholds vary depending on age, condition, temperature, and other factors. Generally adult oysters require salinity levels above 3 parts per thousand (ppt), thrive at 12 to 20 ppt, and are adversely affected by diseases, predators, and algal blooms at seawater salinity conditions. "Dermo", implicated as a cause of 50 percent of adult oyster mortality in Florida, is limited to salinities greater then 9 ppt (Quick and Mackin, 1971; Mackin, 1962).

Estuarine Benthic Communities

Benthic macro invertebrate communities in the St. Lucie Estuary and the Indian River Lagoon are sensitive to bottom type, water quality, and salinity fluctuations. A decline in diversity of benthic organisms and the spread of pollution-tolerant macro invertebrates, such as the polychaete worm (*Glycinde solitaria*), is often one indicator of deteriorated water quality in the estuary and lagoon. Furthermore, the fluctuation between periods of high and low discharge causes alternating shifts between estuarine and freshwater species (Haunert and Startzman, 1985).

Haunert and Startzman (1985) found that an overall reduction of 44 percent of the benthic macro invertebrates occurred during a 3-week experimental freshwater release of 2,500 cubic feet per second (cfs). The greatest change in benthic species composition occurred in the newly created oligohaline zone (0.5 to 5 ppt). In this zone, the freshwater midge (*Chironomus crassicaudatus*) increased dramatically. Additionally, six freshwater species were introduced and at least four estuarine species were lost from the shifted oligohaline zone.

Changes in biodiversity and speciation in the benthic communities brought about by restoration is a hard thing to estimate. It is best illustrated in a study in the Indian River Lagoon by Virnstein (1990). He found that at the meter scale, sea grass beds in the Indian River Lagoon can contain three times the density of macro invertebrates found in unvegetated sediments only a few meters away. At a scale of centimeters, 2 core samples taken next to each other in an apparently homogeneous habitat, often differ in density of macro invertebrates by a factor of 2 or 3.

Salinity Envelop

The estuarine environment is sensitive to freshwater inputs. Modifications to the volume, distribution, circulation, or temporal patterns of freshwater discharges can place severe stress upon the entire ecosystem (Steward et al., 1994). Salinity patterns effect productivity, population distribution, community composition, predator-prey relationships, and food web structure in the inshore marine habitat. Salinity is the master ecological variable that controls important aspects of community structure and food web organization in coastal ecosystems (Myers and Ewel, 1990).

In order to develop an environmentally sensitive plan for the St. Lucie Estuary watershed, biological and physical information was needed to determine a desirable range of flows to the estuary. In 1975, South Florida Water Management District (SFWMD) began baseline investigations to determine the seasonal presence of biota and to document the short-term reactions of estuarine organisms under various salinity conditions during controlled regulatory releases and watershed runoff events (Haunert and Startzman, 1980).

In 1987, the SFWMD research began to support the application of a resource-based management strategy similar to the valued ecosystem component (VEC) approach developed by the United States Environmental Protection Agency (USEPA, 1987) as part of its National Estuary Program. Through this strategy, management objectives are attained by providing a suitable salinity and water quality environment for key species. This approach assumes that environmental conditions suitable for the VEC will also be suitable for other desirable species and that enhancement of the VEC will lead to enhancement of other species.

Utilizing the application of the resource-based management strategy or the VEC approach, a favorable range of inflow and related salinity was established for juvenile marine fish and shellfish, oysters, and submerged aquatic vegetation (Haunert and Konyha, 2001). This favorable range of flows is referred to as the "salinity envelop". A salinity envelop of 350 to 2,000 cfs was established for the St. Lucie Estuary based on previous research on fish and shellfish, as well as on predicted monthly mean salinity from various inflows at designated areas. A family of curves for salinity in the St. Lucie Estuary was obtained by providing a salinity model with constant inflows until a steady salinity gradient was obtained. Using the family of curves, preferred areas, and preferred salinity for oysters and submerged aquatic vegetation, the salinity envelope can been seen. This provides a method to predict where healthy populations of the VEC would exist if the favorable range of flows and salinity is not violated beyond the frequency that is attributed to natural variation of flows from the watershed. A geographic information system was utilized to define specific locations within the designated VEC distributions. Factors in addition to salinity that were considered for oysters and submerged aquatic vegetation included appropriate depth and type of sediment.

Although the initial salinity envelope defined a range of flows desirable for the VEC and provided useful flow management guidelines, a more detailed understanding of environmentally friendly flows was needed to develop a watershed management plan. The distribution of flows within the range of desirable flows needed to be defined as well as the "acceptable" frequency of violations of desired range. In other words, the full distribution and timing of flows from the watershed that accounts for the natural variation of flows needed to be determined.

Fortunately, recent advances have been made in flow analysis. It is now understood that native aquatic biodiversity depends on maintaining or creating some semblance of natural flow variability and that native species and natural communities will perish if the environment is pushed outside the range of natural variability. Where rivers are concerned, a natural flow paradigm is gaining acceptance. It states “the full range of natural intra- and interannual variation of hydrologic regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems” (Richter et al., 1997). A similar paradigm is being developed for estuaries. In riverine estuaries, like the St. Lucie, it seems reasonable to evaluate both flows and salinity with respect to their multiple forms of variation. The full range of natural intra- and interannual variation of salinity regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of estuarine ecosystems (Estevez, 2000).

Due to significant improvements in our understanding of St. Lucie Estuary watershed flows, estuary salinity, and the need to go beyond establishing a favorable range of favorable flows, a reassessment of the flow distribution for the St. Lucie Estuary is required to establish a target flow distribution. St. Lucie Estuary watershed flow distribution targets should ensure the protection of the salinity-sensitive biota in the estuary. It is assumed that species diversity in the St. Lucie Estuary requires the hydrology to have characteristics of a natural system and that the monthly flow distribution is a critical hydrologic characteristic. Particularly, the frequency of low monthly flows and high monthly flows should be similar to that of a natural system.

Table A-1 summarizes the flow distribution by range of the three “natural distributions” analyzed and used for comparison to the “current condition.” The current condition is represented by the modeled watershed runoff, which was based on 1995 land use conditions. The Natural Systems Model (NSM) developed for the St. Lucie Estuary watershed and the Hydrologic Simulation Program FORTRAN (HSPF) estimation of predevelopment conditions in the St. Lucie Estuary watershed and Peace River represents the natural watershed conditions in the Peace River Florida watershed. (Haunert and Konyha, 2001).

Submerged Aquatic Vegetation Distribution, Abundance, and Health

The submerged sea grasses and freshwater macrophytes provide habitat and nursery grounds for many fish and invertebrate communities (Gilmore, 1977, 1988; Gilmore et al., 1981, 1983; Stoner, 1983) and they are food sources for trophically and commercially important organisms (Dawes et al., 1995; Virnstein and Cairns, 1986). Other important roles of submerged aquatic vegetation include benthic-based primary productivity and sediment stabilization (Stoner 1983; Virnstein et al., 1983; Gilmore, 1987; Woodward-Clyde, 1998). Sea grass meadows have been described as the marine analog of tropical rain forests because of their structural complexity, biodiversity, and productivity (Simenstad, 1994). In the Indian River Lagoon, sea grasses provide the ecological basis for a fishery industry worth approximately one billion dollars a year (Virnstein and Morris, 1996).

Table A-1. List of Natural and 1995 Base Case Flow-Frequency Distributions Based on 1965-1995 Climate

Flow Range		Probability in Each Range (percent)			
cfs	**acre-feet per meter**	**NSM (target)**	**HSPF**	**Peace River**	**1995 Base Case**
< 350	< 21,130	54.8	47.6	51.9	31.2
350 to 680	21,130 to 41,053	17.7	19.9	20.4	24.2
680 to 1,010	41,053 to 60,976	6.5	9.7	12.6	12.1
1,010 to 1,340	60,976 to 80,898	6.5	5.9	4.3	8.9
1,340 to 1,670	80,898 to 100,821	4.3	4.0	4.6	7.8
1,670 to 2,000	100,821 to 120,744	3.0	4.8	2.2	4.3
2,000 to 3,000	120,744 to 181,116	4.6	5.9	2.4	7.5
> 3,000	> 181,116	2.7	2.2	1.6	4.0
Average Annual Runoff (inches per year)		11.3	14.6	10	16.1

In a field study conducted by Woodward-Clyde in 1997, the only significant submerged aquatic vegetation beds in the St. Lucie Estuary occurred in the lower estuary near Hell Gate Point. Shoal grass *(Halodule wrightii)* was the dominant species throughout most of this area, with Johnson's sea grass (*Halophila johnsonii)* as the secondary species. The only other documented occurrences of submerged aquatic vegetation during that study was a very small amount of widgeon grass *(Ruppia maritima)*, wild celery (*Vallisneria americana)*, and common water nymph (*Najas guadalupensis*) in the South Fork of the estuary as well as a small area of widgeon grass in the North Fork. Additional sea grasses that are important in the Indian River Lagoon include three *Halophila* species (including the federally listed *Halophila johnsonii*), *Syringodium*, and *Thalassia*.

In a sea grass change analysis of the southern Indian River Lagoon, the 47-mile portion of the lagoon was divided into five segments. A preliminary target of the SWIM sea grass program is to restore and maintain sea grasses to a depth of 5.6 feet lagoonwide (Virnstein and Morris, 1996). Between 1992 and 1999, the maximum southern Indian River Lagoon sea grass acreage (9,864) occurred in 1996, representing approximately 50 percent of the target acreage. The lowest acreage mapped during this period occurred in 1999 when sea grass covered approximately 39 percent (7,808 acres) of the target area. To provide a generalized overview of sea grass health and trends for the entire project area, results for the entire southern Indian River Lagoon region are presented in **Tables A-2** and **A-3**. However, trends observed for the southern Indian River Lagoon as a whole do not necessarily reflect sea grass health and trends for individual segments. Accordingly, results for each segment are also presented in the tables and discussed in more detail in *Southern Seagrass Change Analysis (*Robbins and Conrad, 2001).

All species of submerged aquatic vegetation respond negatively to rapidly changing salinity. Decreased light penetration that results from silt, turbidity, color, and phytoplankton blooms further stresses these plant communities. The result has been a decline in the spatial coverage of beds of submerged aquatic vegetation in the estuary and lagoon (Woodward-Clyde, 1998). The St. Lucie Estuary GIS Application Model developed by Woodward-Clyde for the SFWMD in 1998, identifies major areas of the

Table A-2. Southern Indian River Lagoon Sea Grass (1986–1999) and Sea Grass Target Acreage

Lagoon Segment Number	Total Sea Grass Acreage per Mapping Year						Target Acreage
	1986	1989	1992	1994	1996	1999	
1	-	-	365	341	303	320	324
2	-	-	413	281	136	134	870
3	1,806	1,279	1,513	1,571	1,589	1,520	5,469
4	3,916	4,815	4,273	5,007	5,187	2,856	8,833
5	2,471	2,435	2,310	2,307	2,649	2,978	4,303
TOTAL	8,193	8,529	8,874	9,507	9,864	7,808	19,799

Table A-3. Key Sea Grass Change Locations

Segment	Location	1986 - 1989	1989 - 1992	1992 - 1994	1994 - 1996	1996 - 1999
1	Western shore of Hobe Sound	No Data	No Data	Losses along deep edge of sea grass beds	Losses in coves	Minimal change
2	Hole in the Wall	No Data	No Data	Major losses	Minor gains	Minor gains
	Great Pocket	No Data	No Data	Losses along eastern and western shores	Major losses throughout	Minimal change
	Pecks Lake and North Jupiter Narrows	No Data	No Data	Losses in northeastern corner of Pecks Lake	Major loss in North Jupiter Narrows and Pecks Lake	Few sea grasses remain in area
	Northern Hobe Sound	No Data	No Data	Major losses eastern shore	Minimal change	Minimal change
3	Western shore opposite Nettles Island	Major losses	Continued loss	Minimal change	Minimal change	Minimal change
	Eastern shore south of Nettles Island	Gains and losses	Additional losses	Gains and losses	Additional losses	Gains and losses
	Joes Point	Gains and losses	Minor gains and losses	Minor losses	Major gains	Minor losses
4	Eastern shore: Bear Point to Herman Bay	Major gains	Minor gains and losses	North end gains; south end losses	Gains offshore; losses near shore	Major losses (most of “loss” area mapped as algae)
	Western shore	Major loss along deep edge of sea grass beds	Minor gains and losses	Minor gains	Minor losses	Minor losses and gains
5	Western shore: north and south of HBOI	Major gains	Minor losses	Minor losses	Minor gains	Minor gains
	Eastern shore: west of Garfield Cut	Major losses	Minor gains	Minor gains	Minor losses	Minor gains and losses
	Western shore across from Fort Pierce Cut	Major losses	Minor gains	Minor losses	Minor gains and losses	Minor gains and losses

estuary that would be suitable for sea grass establishment were it not for the above impacts. Sea grass loss negatively impacts fish and invertebrate communities. Also, it results in the destabilization of sediments and a shift in primary productivity from benthic macrophytes to phytoplankton, which provide negative feedback to further diminish sea grass beds (Woodward-Clyde, 1998).

Estuarine Fish Communities/Sport and Commercial Fisheries

The St. Lucie Estuary and Indian River Lagoon provide habitats and nursery grounds for a variety of estuarine fish communities (Gilmore, 1977; Gilmore et al., 1983). Species richness in many of the fish communities of the estuary and lagoon has declined since the 1970s when baseline data were collected. In addition to the general decline in species richness, specific fish communities appear to be affected by salinity and habitat changes.

Submerged aquatic vegetation communities provide nursery ground habitat for juvenile stages of reef and recreationally important fishes in the St. Lucie Estuary and Indian River Lagoon (Lewis, 1984; Virnstein et al., 1983). This community includes mutton, yellowtail and lane snappers, yellowtail parrot fish, gag grouper, sailor's choice grunt, tarpon, snook, jack crevele, spotted sea trout, and redfish. The distribution of juveniles of these species indicates the distribution of stenohaline and stenothermic salinity and temperature conditions in sea grass beds. Sea grass loss and alterations in salinity zonation diminish the habitats suitable as nursery grounds for juvenile reef fish species. Massive freshwater releases from the St. Lucie Canal in the winter of 1998 created significant incidences of fish disease and mortality and toxic dinoflagellate blooms. It also reduced the overall biodiversity of estuarine and freshwater fish communities within the Indian River Lagoon for several months following the release (Gilmore personal data and observations along Bessie Cove, Indian River Lagoon, May 1998, relative to Gilmore 1987; 1988).

The prevalence of diseased and abnormal fish is high in the St. Lucie Estuary. Roughly 15 percent of the fish caught by the National Marine Fisheries Service in the outer estuary and nearshore reef have been visibly abnormal in some way (Browder, personal communication, 2000). The frequency of abnormalities of all types appears to have increased in recent years (Browder et al., 1997; Fournie et al., 1996; Gabriel et al., 1999; Gassman et al., 1994). Although further study, which is currently under way, is needed reach a definitive conclusion, a link between these abnormalities and an increase in the input of toxins, including pesticides and their residues, is suspected to be a major contributing factor.

Ichthyoplankton recruitment into the St. Lucie Estuary and Indian River Lagoon is diminished due to flushing that results from regulatory discharges during key times of the year (Gaines and Bertness, 1992). Estuarine fish species that are negatively affected include the spotted sea trout, snook, the opossum pipefish, and lower trophic level fishes. Snook juvenile settlement rates at specific sites provide a measure of ichthyoplankton recruitment. The spotted sea trout is an estuarine-dependant species that is specifically associated with sea grass beds in the estuary and lagoon. Postlarval and juvenile densities in representative sea grass beds, particularly shoal grass, reflect seasonal salinity and hydrology changes, sea grass bed recovery, and presumably the sports catch of the spotted sea trout.

The opossum pipefish appears to be an indicator of both estuarine and freshwater conditions in the St. Lucie Estuary. Ambient water temperatures and predictable ocean current limit effective breeding of opossum pipefish populations to the Loxahatchee, St. Lucie, and St. Sebastian Rivers of the Indian River Lagoon (Gilmore, 1999). The pipefish is presently a candidate for threatened species listing. Adult opossum pipefish live in freshwater bank vegetation, primarily *Polygonum* and *Panicum* beds. Populations at representative sites appear to be indicators of beneficial wet and dry season salinity conditions. Recruitment of the pipefish in the St. Lucie River occurs during a period of low water flow (through May). Therefore, the November winter release of large volumes of fresh water is atypical and likely to have a deleterious impact on juvenile pipefish movement upstream during this period. (Gilmore, 1999)

Although harvesting of fish and shellfish by the human population of the region has been shown to extend at least 8,000 years back in time to the Ais and Timucuan Indians, the first commercial fisheries did not develop until the 1890s. In a detailed report done by Woodward-Clyde in 1994, it is noted that a shift in species composition of finfish appears to have taken place with a higher proportion of lower priced species being taken more recently. The increased harvest of species such as menhaden and mullet may also have an effect on the overall ecology and productivity of the lagoon. One species, the spotted sea trout, has shown a steady and significant decline (over 50 percent) in landing from 1962 to 1988. This species is almost entirely dependent on the lagoon throughout its life cycle, so its decline may be indicative of adverse conditions within the lagoon. Recreational fishing is continually expanding with the growth of both full-time residents and tourists. The number of fishing trips by residents alone increased from 806,067 in 1970 to 1,811,815 in 1990 and is estimated to increase to 2,890,448 by 2010 (Woodward-Clyde, 1994).

Shoreline Habitat

Mangrove wetlands, forested floodplain, and the emergent bank vegetation of tributaries of the St. Lucie Estuary and Indian River Lagoon support fish and macro invertebrate communities and prevent siltation due to bank erosion. These shoreline habitats have decreased in spatial extent and in function through habitat loss and the loss of connectivity of presently isolated floodplain and shoreline plant communities. A significant portion of the floodplain of the North Fork of the St. Lucie River is completely or partially isolated from the river's main branch because of dredging conducted during the 1920-1940s. The United States Army Corps of Engineers dredging operations in the North Fork commenced in 1922 and were proceeded by mapping of the watercourse in 1919 (Dames and Moore, 1996). As a result, certain natural communities including floodplain swamp, floodplain forest, hydric hammock, and oxbows (backwater river and stream) from the original watercourse are not fully connected to the existing main branch. A significant portion of the river's natural filtration of waterborne nutrients is not utilized to its full capacity. Pilot projects are under way to reconnect mangrove and freshwater wetlands in the Indian River Lagoon and channelized upper reaches of the North and South Forks.

PERFORMANCE MEASURES AND TARGETS

In modeling, the effectiveness of a set of alternative management strategies is evaluated using performance measures. Performance measures quantify how well or how poorly a set of alternatives meets a specific target. Good performance measures have the following features: they are quantifiable; they have a specific target; they indicate when that target has been reached; and they measure the degree of improvement toward the target when it has not been reached. The restoration targets that are trying to be achieved in the St. Lucie Estuary and the Indian River Lagoon are discussed below for each attribute.

Nearshore Reef

Target: Reduce siltation rates to natural levels on reefs off the St. Lucie and Fort Pierce Inlets by reducing the silt carried by freshwater plumes that result from high discharge events from both the St. Lucie Estuary watershed and Lake Okeechobee

Target: Reduce salinity fluctuations on reefs off the St. Lucie and Fort Pierce Inlets by eliminating the freshwater plumes reaching the reefs that result from high discharge events from both the St. Lucie Estuary watershed and Lake Okeechobee

Target: Restore coral, fish, and macro invertebrate community structure and biodiversity of reefs to the conditions documented in baseline data collected in the 1970s

Oysters

Target: Reestablish approximately 900 acres of healthy oysters in the St. Lucie Estuary using the St. Lucie Estuary GIS Application Model to indicate areas most likely to support the reestablishment of oysters

Estuarine Benthic Communities

Target: Increase species richness, abundance, and diversity of benthic species to that typically found in a healthy estuarine community

Salinity Envelope

High Flows

Target: Decrease the numbers of occurrences of flows between 2,000 cfs and 3,000 cfs to less than 4.6 percent of the time

Target: Decrease the number of occurrences of flows greater than 3,000 cfs to less than 2.7 percent of the time

Low Flows

The modeling shows that the current conditions (1995 Base Case) are within the target range for low flow conditions as predicted by the NSM

Target: Keep the number of occurrences of flows less than 350 cfs to less than 54.8 percent of the time

Submerged Aquatic Vegetation

Target: Increase coverage of *Halodule*, *Ruppia*, and *Vallisneria* in the St. Lucie Estuary to include all areas (approximately 920 acres) that are indicated to be suitable habitat based on the St. Lucie Estuary GIS Application Model

Target: Increase coverage of beds of *Halodule*, *Ruppia*, *Syringodium*, *Thalassia*, and the three *Halophila* species, including *H. johnsonii*, in the Indian River Lagoon at depths down to 5.6 feet

Estuarine Fish Communities

Species Richness/Diversity

Target: Increase species richness at benchmark locations, such as Bessey Cove, to levels equaling or exceeding those in the historic (1970s) database and increase species richness above present baseline conditions in other representative sample sites

Incidence of Abnormalities

Target: Decrease the incidence of all types of fish abnormalities to less than one percent in the St. Lucie Estuary and Indian River Lagoon

Juvenile Reef and Recreationally Important Fish

Target: Increase representation of juvenile stages of reef and recreationally important fishes, including the silver snapper species (mutton, yellowtail, and lane), parrot fish, gag grouper, sailor’s choice, snook, redfish, and spotted sea trout from present baseline conditions

Lower Trophic Level Fishes

Target: Increase abundance of mullet, menhaden, and anchovy on catch per unit effort to historic (1970s) baseline conditions

Spotted Sea Trout

Target: Increase postlarval and juvenile densities in representative sea grass beds, particularly shoal grass, from present baseline conditions

Snook

Target: Increase juvenile settlement rates of the common and fat snook at representative sites in the St. Lucie Estuary from present baseline conditions

Redfish

Target: Increase abundance of juvenile and adult redfish at representative sites in the St. Lucie Estuary and Indian River Lagoon from baseline conditions

Opossum Pipefish

Target: Increase populations of adult pipefish in *Polygonum* and *Panicum* beds of bank vegetation at representative sites in freshwater tributaries of the St. Lucie Estuary to levels equaling or exceeding those in baseline surveys conducted in the 1970s

Target: Increase seasonal densities of juvenile pipefish in samples in the St. Lucie Estuary

Shoreline Habitat

Target: Increase spatial extent of mangrove and emergent shoreline plant communities through replanting

Target: Reconnect approximately 100,000 linear feet of isolated river floodplain and remove and control exotics on the reconnected floodplain

REFERENCES

Bahr, L.M., and W.P. Lanier. 1981. *The Ecology of Intertidal Oyster Reefs of the South Atlantic Coast: A Community Profile*. FWS/OBS-81/15, Office of Biological Services, United States Fish and Wildlife Service, Slidell, LA.

Browder, J.A., and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of freshwater to estuaries. In: Cross, R. (ed), *Proceedings of the National Symposium on Fresh Water Inflow to Estuaries*, September 1980, San Antonio, TX, pp 403-430.

Browder, J.A., N.P. Gassman, M.C. Schmale, and C. Sindermann. 1997. Restoration success criteria based on prevalence of abnormalities in fish. In: *Science Subgroup. Ecological and Precursor Success Criteria for South Florida Ecosystem Restoration*.

Science Subgroup Report to the Working Group of the South Florida Ecosystem Restoration Task Force. Available from the Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL, 33149.

Cake, E.W., Jr. 1983. *Habitat Suitability Index Models: Gulf of Mexico American Oyster.* FWS/OBS-82/10.57, Biological Services Program, United States Fish and Wildlife Service.

Caline, B., Y. Gruet, NEED OTHER AUTHORS. 1992. *The Sabellarid Reefs in the Bay of Mont*. Saint-Michel, France. FOS contributions to Marine Science.

Chamberlain, R., and D. Hayward. 1996. Evaluation of water quality and monitoring in the St. Lucie Estuary, Florida. *Water Resources Bulletin* 32(4):681-695.

Dames and Moore. 1996.

Dawes, C.J., D. Hanisak, and W. J. Kenworthy. 1995. Seagrass biodiversity in the Indian River Lagoon. *Bulletin of Marine Science* 57(1):59-66.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R.A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *BioScience* 43(2):86-94.

Estevez, E.D. 2000. *A Review and Application of Literature Concerning Freshwater Flow Management in Riverine Estuaries*. Technical Report Number 680, Mote Marine Laboratory, Sarasota, FL.

Fonsceca, M.S., and J.S. Fisher. 1986. A comparison of canopy friction and sediment movement between four species of sea grass and with reference to their ecology and restoration. *Marine Ecology Progress Series* 29:15-22.

Fournie, J.W., J.K. Summers, and S.B. Weisberg. 1996. Prevalence of gross pathological abnormalities in estuarine fishes. *Trans. Am. Fish. Soc.* 125:581-590.

Gabriel, N.F. 1999. Externally visible fish abnormalities from laboratory and field studies. In: Ranier, R. (ed), *FishBase 99 and FishBase 2000*, CD-ROM. International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines. Also Contribution Number PRD-98/99-11, Southeast Fisheries Science Center, National Marine Fisheries Service, National Ocean and Atmospheric Administration, Miami, FL.

Gabriel et al. 1999.

Gaines, S.D., and M.D. Bertness. 1992. Dispersal of Juveniles and Variable Recruitment in Sessile Marine Species. *Nature* 360:579-580.

Gassman, N.J., L.B. Nye, and M.C. Schmale. 1994. Distribution of abnormal biota and sediment contaminants in Biscayne Bay, Florida. *Bulletin of Marine Science* 54:929-943.

Gilmore, R.G. 1977. Fishes of the Indian River lagoon and adjacent waters. *Florida. Bulletin of the Florida State Museum* 22:101-147.

Gilmore, R.G. 1987. Fish, macrocrustacean, and avian, population dynamics and cohabitation in tidally influenced impounded subtropical wetlands. In: Whitman, W.R., and W.H. Meredith (eds), *Proceedings of a Symposium in Waterfowl and Wetland Management in the Coastal Zone of the Atlantic Flyway*, Delaware Department of Natural Resources and Environmental Control, Dover, DE.

Gilmore, R.G. 1988. *Subtropical Seagrass Fish Communities, Population Dynamics, Species Guilds and Microhabitat Associations in the Indian River Lagoon*. Ph.D. Dissertation, Department of Biological Sciences, Florida Technical, Melbourne, FL.

Gilmore, R.G. 1995. Environmental and biogeographic factors influencing ichthyofaunal diversity: Indian River Lagoon. *Bulletin of Marine Science* 57(1): 155-157.

Gilmore, R.G. 1999. *Life History and Critical Habitat/Environment of Opossum Pipefish: A Population Viability Analysis*. Estuary, Coastal and Ocean Science, Inc., Vero Beach FL.

Gilmore, R.G., and P.A. Hastings. 1983. Observations on the ecology and distribution of certain tropical peripheral fishes in Florida. *Florida Scientist* 46:31-51.

Gilmore, R.G., C.J. Donahoe, D.W. Cooke, and D.J. Herema. 1981. Fishes of the Indian River Lagoon and Adjacent Waters, Florida. Technical Report 41, Harbor Branch Foundation, Harbor Branch Oceanographic Institute, Fort Pierce, FL.

Gilmore, R.G., C.J. Donahoe, and D.W. Cooke. 1983. Observations of the distribution and biology of the east Florida populations of the common snook, *Centropomis undecimalis* (Bloch). *Florida Scientist*, special supplement 45(4).

Gore, R.H., L.E. Scotto, and L.J. Becker. 1978. Community composition, stability and trophic partitioning in decapod crustaceans inhibiting some subtropical sabellariid worm reefs. Bulletin of Marine Sciences 28:221-248.

Gunter, G., and G.E. Hall. 1963. Biological investigations of the St. Lucie Estuary (Florida) in connection with Lake Okeechobee discharges through the St. Lucie Canal. G*ulf Research Reports* 1(5), Ocean Springs, MS.

Haunert, D.E. 1987. *A Proposed Supplemental Water Management Strategy to Enhance Fisheries in the St. Lucie Estuary, Florida*. Unpublished, South Florida Water Management District, West Palm Beach, FL.

Haunert, D.E. 1988. *Sedimentation Characteristics and Toxic Substances in the St. Lucie Estuary, Florida*. Technical Publication 88-10, South Florida Water Management District, West Palm Beach, FL.

Haunert, D.E., and K. Konyha. 2001. *Establishing St. Lucie Estuary Watershed Inflow Targets to Enhance Mesohaline Biota*, in preparation.

Haunert, D.E., and R.J. Startzman. 1980. *Some Seasonal Fisheries Trends and Effects of a 1000 cfs Freshwater Discharge on the Fishes and Macroinvertebrates in the St. Lucie Estuary, Florida*. Technical Publication 80-3, South Florida Water Management District, West Palm Beach, FL.

Haunert, D.E., and R.J. Startzman. 1985. *Some Short Term Effects of a Freshwater Discharge on Biota of the St. Lucie Estuary, Florida*. Publication 85-1, South Florida Water Management District, West Palm Beach, FL.

Jaap, W.C., and P. Hallock. 1991. Coral Reefs In: Myers, R.L., and J.J. Ewel (eds) *Ecosystems of Florida*, Chapter 17, University of Central Florida Press, Orlando, pp 574-616.

Kemp, W.M., R.R. Twilley, J.C. Stevenson, W. Boynton, and J.C. Means. 1983. The decline of submerged vascular plants in upper Chesapeake Bay: Summary of results concerning possible causes. *Marine Tech. Soc. J.* 17:78-89.

Kennish, M.J. 1990. *Ecology of Estuaries*. Volume 2, CRC Press Boca Raton, FL.

Kirtley, D.W., and W.F. Tanner. 1968. Sabellariid worms: builders of a major reef type. *J. Sediment Petrol.* 38:73-78.

Klump, D.W., J.S. Salita-Espinosa, and M.D. Fortes. 1992. The Role of Epiphytic Periphyton and Macroinvertebrate Grazers in the Trophic Flux of a Tropical Seagrass Community. *Aquatic Biology* 43:327-349.

Lewis, F.G., III. 1984. Distribution of macrobenthic crustaceans associated with *Thalassia, Halodule* and bare sand substrata. *Marine Ecology Progress Series* 19:101-113.

Loosanoff, V.L., and Nomejko. 1951. Existence of Physiologically different races of oysters. *Crassostrea virginica. Biological Bulletin* (Woods Hole) 90(3):244-264.

Mackin, J.G. 1962. Oyster disease caused by *Dermocystidium marinum* and salinity. *Proceedings of the National Shellfisheries Association* 46:116:128.

Mackin, J.G., and S.H. Hopkins. 1962. Studies on Oyster mortality in relation to natural environments and to oils fields in Louisiana. *Publications of the Institute of Marine Science, University of Texas*, 8:132-229.

Morris, L., and D. Tomasko. 1993. *Draft Proceedings and Conclusions for the Submerged Aquaitic Vegetation Initiative and the Photosynthetic Active Radiation Workshops*. Indian River Lagoon National Estuary Program, Melbourne, FL.

Myers, R.L., and J.J. Ewel. 1990. *Ecosystems of Florida*. University Presses of Florida, Gainesville, FL.

Nelson, W.G., K.D. Cairns, and R.W. Virnstein. 1982. Seasonal and spatial patterns of seagrass-associated amphipods of the Indian River Lagoon, Florida. *Bulletin of Marine Science* 32:121-129.

Nielson, S., and B. Eggers, and S. Collins. 2000. The Influence of Seawalls and Revetments on the Presence of Seagrass in the Indian River Lagoon: A preliminary Study. Environmental Management Systems, Inc.

Pearse, A.S., and G.W. Wharton. 1938. The Oyster Leech *Stylocus inimicus* Palombi associated with oysters on the coasts of Florida. *Ecological Monographs* 8:605-655.

Perkins, E.J. 1974. *The Biology of Estuaries and Coastal Waters*. Academic Press, London, United Kingdom.

Pitt, W.A., Jr. 1972. S*ediment Loads in Canals 18, 23 and 24 in Southeastern Florida*. Open File Report 72013, United States Geological Survey, Tallahassee, FL.

Quick, J.A., Jr., and J.G. Mackin. 1971. *Oyster Parasitism by Labyrinthomyxa Marina in Florida*. Professional Paper Series Number 13, Marine Research Laboratory, Florida Department of Natural Resources, St. Petersburg, FL.

Reed, J.K. 1980. Contribution and structure of deep water *Oculina varicosa* coral reefs off central eastern Florida, USA. *Bulletin of Marine Science* 30:667-677.

Reed, J.K. 1981. In situ growth rates of the scleractinian coral *Oculina varicosa* occurring with zooxanthellae on 6-m reefs and without on 80-m banks. *Proc. Int. Coral Reef Cong.*, 4th, Manila 2:201-206.

Reed, J.K. 1985. Deepest distribution of Atlantic hermatypic corals. *Proc. Int. Coral Reef Symp.*, 5th, Tahiti 6:249-254.

Richter, B.D., J.V. Baumgartner, R. Wiginton, and D.P. Braun. 1997. How much water does a river need? *Freshwater Biology* 37:237-249.

Robbins, R., and C. Conrad. 2001. *Southern Indian River Lagoon Seagrass Change Analysis*. In prep.

Sargent, F.J., T.J. Leary, D.W. Crewz, and C.R. Kruer. 1995. *Scarring of Florida's Seagrasses: Assessment and Management Options*. TR-1, Florida Marine Research Institute, Florida Department of Environmental Protection, St. Petersburg, FL.

Shrader, D.C. 1984. *Holocene Sedimentation in a Low Energy Microtidal Estuary, St. Lucie River, Florida*.

Simenstad, C.A. 1994. Faunal association and ecological interactions in seagrass communities of the Pacific Northwest. In: Wyllie-Echeverria, S., A.M. Olsen, and M.J. Hershman (eds), *Seagrass Science and Policy in the Pacific Northwest: Proceedings of a Seminar Series* (SMA 94-1). EPA 910/R-94-004, Seattle, WA, pp. 1-17

Steward, J., R.W. Virnstein, D.E. Haunert, and F. Lund. 1994. *Surface Water Improvement and Management (SWIM) Plan for the Indian River Lagoon, Florida*. St. Johns River Water Management District, Palatka, FL, and South Florida Water Management District, West Palm Beach, FL.

Stoner, A.W. 1983. Distribution of fishes in seagrass meadows: role of macrophyte biomass and species composition. *Fisheries Bulletin* 81(4):837-846.

Thayer, G.W., W.J. Kenworthy, and M.S. Fonseca. 1984. *The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile*. FWS/OBS-84/02, United States Fish and Wildlife Service, United States Department of the Interior, Washington, D.C.

Tomasko, D.A., C.J. Dawes, M.O. Hall. 1996. The effects of anthropogenic nutrient enrichment on turtle grass (*thalassia testudinum)* in Sarasota Bay, FL. *Estuaries* 19(2B):448-456.

USACE and SFWMD. 1999. *Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental*

Impact Statement. United States Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL.

USEPA, 1987. *Estuary Program Primer*, Office of Marine and Estuarine Protection, United States Environmental Protection Agency, Washington, D.C.

Virnstein, R.W. 1990. The large spatial and temporal biological variablitiy of the Indian River Lagoon. *Florida Science*. 53(3):249-256.

Virnstein, R.W., and D. Campbell. 1987. Biological Resources. In: Steward, J.S., and J.A. VanAtman, *Indian River Lagoon Joint Reconnaissance Report*, St. Johns River Water Management District, Palatka, FL, and South Florida Water Management District, West Palm Beach, FL, pp. 6-1 to 6-115.

Virnstein, R.W., and K.D. Cairns. 1986. *Seagrass maps of the Indian River Lagoon, Final Report*. Report to the St. Johns River Water Management District, Palatka, FL, submitted by Seagrass Ecosystems Analysts, Inc., Vero Beach, FL.

Virnstein, R.W., and L.J. Morris. 1996. *Seagrass Preservation and Restoration: a Diagnostic Plan for the Indian River Lagoon*. Technical Memorandum 14, St. Johns River Water Management District, Palatka, FL.

Virnstein, R.W., P.S. Mickkelson, K.D. Cairns, and M.A. Capone. 1983. Seagrass beds versus sand bottoms: the trophic importance of their associated benthic invertebrates. *Florida Scientist* 46:363-381.

Virnstein, R.W., W.G. Nelson, F.G. Lewis III, and R.K. Howard. 1984. Latitudinal patterns in seagrass epifauna: Do patterns exist, and can they be explained? *Estuaries* 7:310-330.

Waas, M.L. 1967. Biological and physiological basis of indicator organisms and communities. In: Olsen, T.A., and F.J. Burgess (eds), *Pollution and Marine Ecology*, Interscience, New York, NY.

Wells, H.W. 1961. The fauna of oyster beds, with special reference to the salinity factor. *Ecological Monographs* 31:239-266.

Wilhm, J.L. 1967. Comparison of some diversity indices applied to populations of benthic macroinvertebrates in a stream receiving organic wastes. *J. Wat. Poll. Cont. Fed.* 39(10):1673-1683.

Wilhm, J.L. 1968. Use of biomass units in Shannon's formula. *Ecology* 49(1):153-156.

Wilhm, J.L. 1970. Range of diversity indices in benthic macroinvertebrate populations. *J. Wat. Poll. Cont. Fed.* 42-5(2): R221-R224.

Wilhm, J.L., and T.C. Dorris. 1968. Biological parameters for water quality criteria. *Bioscience* 18(6):477-481.

Woodward-Clyde. 1994. *Uses of the Indian River Lagoon, Indian River Lagoon National Estuary Program, Melbourne, Florida*. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Woodward-Clyde. 1998. *Distribution of Oysters and Submerged Aquatic Vegetation in the St. Lucie Estuary*. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Zale, A., and S. Merrifield. 1998. *Reef Building Tube Worm*. Department of Zoology, Oklahoma State University, Stillwater, OK.

Zieman, J.C., and R.T. Zieman. 1989. *The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile*. Biological Report 85(7.25), United States Fish and Wildlife Service, United States Department of the Interior, Washington, D.C.